The Presumptions of Science
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The Presumptions of Science

CAN THERE BE "forbidden"—or, as I prefer, "inopportune" knowledge? Could there be knowledge, the possession of which, at a given time and stage of social development, would be inimical to human welfare—and even fatal to the further accumulation of knowledge? Could it be that just as the information latent in the genome of a developing organism must be revealed in an orderly pattern, else disaster ensue, so must our knowledge of the universe be acquired in a measured order, else disaster ensue?

Biological organisms are equipped with many sensors essential to their survival, sensors for heat, cold, pain, thirst, hunger. Social organisms similarly need sensors of peril, particularly as they evolve into new domains—and for these we must use our intelligence, limited as it may be.

Discussion of the possible restraint of inquiry touches a most sensitive nerve in the academic community. If one believes that the highest purpose available to humanity is the acquisition of knowledge (and in particular of scientific knowledge, knowledge of the natural universe), then one will regard any attempt to limit or direct the search for knowledge as deplorable—or worse.

If, however, one believes that there may be other values to be held even higher than the acquisition of knowledge—for instance, general human welfare—and that science and possible other modes of knowledge acquisition should subserve these higher values, then one is willing to (indeed, one must) consider such issues as: the possible restriction of the rate of acquisition of scientific knowledge to an "optimal" level relative to the social context into which it is brought; the selection of certain areas of scientific research as more or less appropriate for that social context; the relative priorities at a given time of the acquisition of scientific knowledge or of other knowledge such as the effectiveness of modes of social integration, or of systems of justice, or of educational patterns.

In short, if one does not regard the acquisition of scientific knowledge as an unquestioned ultimate good, one is willing to consider its disciplined direction. One may, of course, still have grave doubt as to whether mankind can know enough to be able intelligently to guide the rate or direction of the scientific endeavor, but at least one will then accept that we have a responsibility to seek answers—if there be any—to such questions.

The Impact of Science

In 1930 Robert A. Millikan, Nobel Prize winner, founder and long-time leader of Caltech, wrote in an article entitled "The Alleged Sins of Science" that one may "sleep in peace with the consciousness that the Creator has put some foolproof elements into his handiwork, and that man is powerless to do it any titanic physical damage."[1]

To what was Millikan referring? Stimulated by the recombinant DNA controversy, I have looked back to see if there were any similar admonitions or premonitions with respect to the possible consequences of nuclear energy. And there were. Millikan, in 1930, was responding to an earlier writing of Frederick Soddy. In a book entitled *Science and Life* Soddy, who had been a collaborator of Rutherford, had written:

> Let us suppose that it became possible to extract the energy which now oozes out, so to speak, from radioactive material over a period of thousands of millions of years, in as short a time as we pleased. From a pound weight of such substance one could get about as much energy as would be obtained by burning 150 tons of coal. How splendid. Or a pound weight could be made to do the work of 150 tons of dynamite. Ah, there's the rub . . . It is a discovery that conceivably might be made tomorrow in time for its development and perfection, for the use or destruction, let us say, of the next generations, and, which it is pretty certain, will be made by science sooner or later. Surely it will not need this actual demonstration to convince the world that it is doomed if it fools with the achievements of science as it has fooled too long in the past.
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> War, unless in the meantime man has found a better use for the gifts of science, would not be the lingering agony it is today. Any selected section of the world, or the whole of it if necessary, could be depopulated with a swiftness and dispatch that would leave nothing to be desired.[2]

Millikan commented, just prior to his statement quoted above, "Since Mr. Soddy raised the hobgoblin of dangerous quantities of available subatomic energy [science] has brought to light good evidence that this particular hobgoblin—like most of the hobgoblins that crowd in on the mind of ignorance—was a myth . . . The new evidence born of further scientific study is to the effect that it is highly improbable that there is any appreciable amount of available subatomic energy to tap."[3]

So much for scientific prophecy. But it is indeed instructive and also troubling to recognize that our scientific endeavor truly does rest upon unspoken, even unrecognized, faith—a faith in the resilience, even the benevolence, of nature as we have probed it, dissected it, rearranged its components in novel configurations, bent its forms and diverted its forces to human purpose. Scientific endeavor rests upon the faith that our scientific probing and our technological ventures will not displace some key element of our protective environment and thereby collapse our ecological niche. It is a faith that nature does not set booby traps for unwary species.

Our bold scientific thrusts into *new* territories uncharted by experiment and unencompassed by theory must rely wholly upon our faith in the resilience of nature. In the past that faith has been justified and rewarded, but will it always be so? The faith of one era is not always appropriate to the next, and an unexamined faith is unworthy of science. Ought we step more cautiously as we explore the deeper levels of matter and life?

Most states of nature are quasiequilibria, the outcome of competing forces. Small deviations from equilibrium, the result of natural processes or human intervention, are most often countered by an opposing force and the equilibrium restored, at some rate dependent upon the kinetics of the processes, the sizes of the relevant natural pools of components, and other factors. Although we may therefore speak of the resilience of nature, this restorative capacity is finite and is limited in rate.

For example, if the ozone layer of the atmosphere is lightly and transiently depleted by a nuclear explosion or the atmospheric release of fluorocarbons, the natural processes which generate the ozone layer can restore it to the original level within a brief period. However, should the ozone layer be massively depleted—as by extended, large-scale release of fluorocarbons—many decades would be required for its renewal by natural processes, even if the release of fluorocarbons ceased.

Similiarly, the populations of most living creatures can achieve an equilibrium level dependent upon birth rates and upon death rates from various causes. Most species have an excess capacity for reproduction, so that minor additions to the process of their removal (as by the harvesting of fish) cannot appreciably influence the equilibrium population. Patently however, excessive harvesting removing numbers beyond the reproductive capacity of the species will in time bring about its extinction.

In a similar manner lakes and rivers and air basins can absorb and dispose of limited amounts of pollutant but can be overwhelmed by masses beyond their capacity. Once overwhelmed the very agents responsible for disposal of pollution in small quantities may be destroyed, leaving a "dead" sea.

The concept of resilience extends to the planet as a whole and to the impact upon the manifold equilibria upon which the network of life forms depends as we continue to expand our intensive monoculture agriculture, as we continue to increase the total of human energy consumption (the man-made release of energy in the Los Angeles basin is now estimated at about 5 percent of the solar input), as we continue to raise the atmospheric level of CO_2 by combustion of fossil fuel, and so forth.

Because human beings (and most creatures) are adapted by evolution to the near equilibrium states, the resilience provided by the restorative forces of nature has appeared to us to be not only benevolent, but unalterable. Less overt than our faith in the resilience of nature is the faith with which we have relied upon the resilience of our social institutions and their capacity to contain the stress of change and to adapt the knowledge gained by science—and the power inherent in that knowledge—to the benefit of society, more than to its detriment. The fragility of the equilibria underlying social institutions is even more apparent than of the equilibria of nature. Political, economic, and cultural balances have shifted drastically in human history under the impact of new technologies, or new ideologies or religions, of invading peoples, of resource exhaustion, and other changes. Our faith in the resilience of both natural and man-made phenomena is increasingly strained by the acceleration of technical change and the magnitude of the powers deployed.

Physics and chemistry have given us the power to reshape the physical nature of the planet. We wield forces comparable to, even greater than those of, natural catastrophes. And now biology is bringing to us a comparable power over the world of life. The recombinant DNA technology, while significant and potentially a grievous hazard in itself (through the conceivable production, by design or by inadvertance, of new human, animal, or plant pathogens or of novel forms capable of disrupting important biological equilibria), must be seen as a portent of things to come.

The present recombinant DNA technology, which permits the addition or replacement of a few genes in living cells, is but the first prototype of genetic engineering. More powerful means involving cell fusion or chromosome transfer are already close to hand; even more sophisticated future developments appear assured. Since genes determine the basic structures and biological potentials of all living forms, the ultimate potential of genetic engineering for the modification and redesign of plants and animals to meet human needs and desires seems virtually unlimited.

Such capabilities will pose major questions as to the extent to which mankind will want to assume the responsibility for the life forms of the planet. Further, there is no reason to believe the same technology will not be applicable to mankind as well; the capability of human genetic engineering will raise profound questions of values and judgment for human societies.

It seems paradoxical that a living organism emergent from the evolutionary process after billions of years of blind circumstance should undertake to determine its own future evolution. The process is perhaps analogous to that of the mind seeking to understand itself. In both cases it is uncertain whether the attempt can possibly be successful. Nonetheless, at this point perhaps we had best step back and reconsider what it is we are about.

For four centuries science has progressively expanded our knowledge and reshaped our perception of the world. In that same time technology has correspondingly reshaped the pattern of our lives and the world in which we live.

Most people would agree that the net consequence of these activities has been benign. But it may be that the conditions which fostered such a benign outcome of scientific advance and technological innovation are changing to a less favorable set. Changes in the nature of science or technology or in the external society—in either the scale of events or their temporal order—can affect the preconditions, the presumptions, of scientific activity, and can thus alter the future consequences of such activities.

Both quantitative and qualitative changes have surely affected the impact of science and technology upon society. Quantitatively, the exponential growth of scientific activity and the unprecedented magnitude of modern industrial ventures permit the introduction of new technologies (e.g., fluorocarbon sprays) on a massive scale within very brief periods often with unforeseen consequence. Qualitatively, science and technology have been directed increasingly to synthesis—to the formulation of new substances designed for specific human purpose. Thus we have synthetic atoms (plutonium, strontium-90), synthetic molecules (dioxin, kepone, DDT) and now synthetic microorganisms (recombinant DNA). In these activities we introduce wholly novel substances into the planetary environment, substances with which our evolution has not always prepared us to cope.

Can we continue to rely upon the past four centuries as a guide for scientific activity, given these changes? Other human activities of this same era are now increasingly seen in a different hue. The same period witnessed exponential increases in population and in the exploitation of natural resources for material wealth. Few would argue continuance of such trends will be benign.[4] The same era has witnessed the constant acceleration of the rate of change, the increasing dominance of technology in the affairs of men.

The constantly accelerating accretion of knowledge, therefore, may not always be counted as a good. Can circumstances change so as to devalue the net worth of new knowledge? Might a pause or slowdown for consolidation and reflection then be more in order? Indeed, could it be that some knowledge could, at this time, be positively malign? Hard questions, perhaps not answerable, perhaps not the right questions, but they are not answered for 1977 by invoking Galileo or Darwin or Freud. I believe they demand our thought.

I would advance for consideration some propositions that frankly I'm not at all sure I entirely believe. I think that in order to find out what one does believe it is necessary to go beyond what one can readily accept—to explore honestly more extreme and more remote positions so that one's position is based upon intelligent choice, not simple ignorance.

The domain I propose to explore can be indicated by a question. The question is one I have actually raised within the administration at Caltech (and it could as well be raised elsewhere). Institutions such as Caltech and others devote much energy and effort and talent to the advancement of science. We raise funds, we provide laboratories, we train students, and so on. In so doing we apply essentially only one criterion—that it be good science as science—that the work be imaginative, skillfully done, in the forefront of the field. Is that, as we approach the end of the twentieth century, enough? As social institutions, do Caltech and others have an obligation to be concerned about the likely *consequences* of the research they foster? And if so, how might they implement such a responsibility?

For reasons which probably need no elaboration Caltech has been more than reluctant to come to grips with this question. And, indeed, it just may be—and I say this with real sorrow—that scientists are simply not the people qualified to cope with such a question. The basic tactic of natural science is analysis: fragment a phenomenon into its components, analyze each part and process in isolation, and thereby derive an understanding of the subject. In physics, chemistry, even biology, this tactic has worked splendidly.

To answer my question, however, the focus must not be inward but outward, not narrowed but broadened. The focus must be on all the ties of the sciences to society and culture and on the impact of scientific knowledge and technological advancement on all human, indeed all planetary, life.

Consider as an instance the recombinant DNA issue. The natural tendency of the scientist, if he will admit this a problem, is to break it down, to decompose it into individually analyzable situations. If there is a danger, quantitate it: what is the numerical chance of the organisms escaping, of their colonizing the gut, of their penetrating the intestinal epithelium, of their causing disease (what disease)? If you point out that there is a nearly infinite set of possible scenarios of misfortune—that accidents do happen and in unpredictable ways, that humans do err, that bacterial or viral cultures do become contaminated, that indeed aspects of this technology involve inherently unpredictable consequence and hence are not susceptible to quantitative analysis—you are regarded as unscientific.

The consequences of the interaction of known but foreign gene products with the complex contents of a bacterial cell would be difficult enough to predict, much less the consequences of the interactions of unknown gene products, as produced in "shotgun" experiments. Some of these consequences may well modify, in unpredictable ways, the likelihood of the organism's survival or persistence in various environments, its potential toxicity for a host or nearby life forms. It may alter, for instance, an organism's survival in an animal intestine, contrary to our expectations, for we have presumed that we know all factors important for survival there and that no new successful adaptations could emerge.

For complex reasons, consideration of the potential hazards from organisms with recombinant DNA has focused upon immediate medical concerns. That these organisms with unpredictable properties might have impact upon any of the numerous microbiological processes which are important components of our life support systems is simply dismissed as improbable. The fact that these organisms are evolutionary innovations and have within themselves, as do all living forms, the capacity (if they survive) for their own unpredictable future evolutionary development is ignored, or dismissed as mystical.

If you point out that the recombinant DNA issue simply cannot be effectively considered in isolation but must be viewed in perspective and in a larger context as a possible precursor to future technologies available to many elements of society (including totalitarian governments, the military, and terrorist factions) your remarks are regarded as irrelevant to science.

There is an intensity of focus in the scientific perspective which is both its immediate strength and its ultimate weakness. The scientific approach focuses rigorously upon the problem at hand, ignoring as irrelevant the antecedents of motive and the prospectives of consequence.

Viewed objectively such an approach can only make sense if either (1) the consequences are always trivial, which is patently untrue, or (2) the consequences are always benign, that is, if the acquisition of knowledge, of any knowledge at any time, is always good, a proposition one might find hard to defend, or (3) the dangers and difficulties inherent in any attempt to restrict the acquisition of knowledge are so great as to make the unhindered pursuit of science the lesser evil.

In thinking about the impacts of science, we should, perhaps, reflect upon the inverse of the uncertainty principle. Perhaps it might be called the certainty principle. The uncertainty principle is concerned with the inevitable impact of the observer upon the observed, which thereby alters the observed. Conversely, there is an effect of the observed upon the observer. The discovery of new knowledge, the addition of new certainty, which correspondingly diminishes the domain of uncertainty and mystery, inevitably alters the perspective of the observer. We do not see the world with the same eyes as a Newton or a Descartes, or even a Faraday or a Rutherford.

The acquisition of a discipline sharpens our vision in its domain, but too frequently it seems also to blind us to other concerns. Thus immersion in the world of science, with its store of accumulated and substantiated fact, can make the participant intolerant of, and impatient with the uncertainties and nonreproducibilities of the human world. Engrossed in the search for knowledge, scientists tend to adopt the position that more knowledge is the key to the solution to human problems. They may not see that the uses we make of knowledge or the ways in which we organize to use knowledge can, as well, be the limiting factors to the human condition, and they forget that even within science our knowledge and our theories are always human constructs. Moreover, we should always remember (lest we become too secure and even smug) that our knowledge and our theories are ever incomplete.

Of Dubious Merit

To make this discussion more specific let me consider three examples of research that I personally consider to be, on balance, of dubious merit. One is in an area of rather applied research, the second in a very speculative but surely basic area, and the third in the domain of biomedical research, which we most often conceive to be wholly benign.

The first I would cite is current research upon improved means for isotope fractionation. In one technique, one attempts to use sophisticated lasers[5] to activate selectively one isotope of a set. I do not wish to discuss the technology but rather the likely consequence of its success. To be sure, there are benign experiments that would be facilitated by the availability of less expensive, pure isotopes. For some years I wanted to do an experiment with oxygen 18 but was always deterred by the cost.

But does anyone doubt that the most immediate application of isotope fractionation techniques would be the separation of uranium isotopes? This country has recently chosen to defer, at least, if not in fact to abandon, the plutonium economy and the breeder reactor because of well-founded concern that plutonium would inevitably find its way into weapons. We are thus left with uranium-fueled reactors. But uranium 235 can also be made into a bomb. Its use for power is safer only because of the difficulty in the separation of uranium 235 from the more abundant uranium 238. If we supersede the complex technology of Oak Ridge, if we devise quick and ingenious means for isotope separation, then one of the last defenses against nuclear terror will be breached. Is the advantage worth the price?

A second instance I would cite of research of dubious merit, and one probably even more tendentious than the first, relates to the proposal to search for and contact extraterrestrial intelligence.[6] Recent proposals suggest that, using advanced electronic and computer technology, we could monitor a million "channels" in a likely region of the electromagnetic spectrum, "listening" over several years for signals with an "unnatural" regularity or complexity.

I am concerned about the psychological impact upon humanity of such contact. We have had the technical capacity to search for such postulated intelligence for less than two decades, an instant in cosmic terms. If such intelligent societies exist and if we can "hear" them, we are almost certain to be technologically less advanced and thus distinctly inferior in our development to theirs. What would be the impact of such knowledge upon human values?

Copernicus was a deep cultural shock to man. The universe did not revolve about us. But God works in mysterious ways and we could still be at the center of importance in His universe. Darwin was a deep cultural shock to man. But we were still number one. If we are closer to the animals than we thought before, and through them to the rocks and the sea, it does not really devalue man to revalue matter. To really be number two, or number 37, or in truth to be wholly outclassed, an inferior species, inferior on our own turf of intellect and creativity and imagination, would, I think, be very hard for humanity.

The impact of more advanced cultures upon less advanced has almost invariably been disastrous to the latter. We are well acquainted with such impacts as the Spanish upon the Aztecs and Incas or the British and French upon the Polynesians and Hawaiians. These instances were, however, compounded by physical interventions (warfare) and the introduction of novel diseases. I want to emphasize the purely cultural shock. Hard learned skills determinant of social usefulness and positions become quickly obsolete. Less advanced cultures quickly become derivative, seeking technological handouts. What would happen to *our* essential tradition of self-reliance? Would we be reduced to seekers of cosmic handouts?

The distance of the contacted society might, to some degree, mitigate its consequent impact. A contact with a round trip communication time of ten years would have much more effect than one with a thousand years. The likelihood of either is, however, a priori, unknown. Nor is it inconceivable that an advanced society could devise means for communication faster than light.

The proponents of such interactions have considered the consequences briefly. In a 427-page book *Communication with Extraterrestrial Intelligence*[7] sixteen pages comprise a chapter entitled "Consequences of Contact." Opinion therein ranges from "Our obligation is, I feel, to stress that in any sensible way this problem has no danger for human society. I believe we can give a full guarantee of this" to "If we come in contact with some superior civilization this would mean the end of our civilization, although that might take a while. Our period of culture would be finished."

How and by whom should such a momentous decision[8] be made—one that will clearly, if successful, have an impact upon all humanity? Somehow I cannot believe it should be left to a small group of enthusiastic radioastronomers.

My concern here does not extend so far that I would abolish the science of astronomy. If the astronomers in the course of their science come across phenomena that can only be understood as the product of intelligent activity, so be it. But I do not believe that is the same as deliberately setting out to look for such activity with overt pretensions of social benefit.

The third example of research I consider of dubious merit concerns the aging process. I would suggest this subject exemplifies in supreme degree the eternal conflict between the welfare of the individual and the welfare of society and, indeed, the species. Obviously, as individuals, we would prefer youth and continued life. Equally obviously, on a finite planet, extended individual life must restrict the production of new individuals and that renewal which provides the vitality of our species.

The logic is inexorable. In a finite world the end of death means the end of birth. Who will be the last born?

If we propose such research we must take seriously the possibility of its success. The impact of a major extension of the human life span upon our entire social order, upon the life styles, mores, and adaptations associated with "three score and ten," upon the carrying capacity of a planet already facing overpopulation would be devastating. At this time we hardly need such enormous additional problems. Research on aging seems to me to exemplify the wrong research on the wrong problem in the wrong era. We need that talent elsewhere.

Is Restraint Feasible?

If one concedes, however reluctantly, that restraint of some directions of scientific inquiry is desirable, it is appropriate to ask if it is feasible and, if so, at what cost.

Some of my colleagues, not only in biology but in other fields of science as well, have indicated to me that they too increasingly sense that our curiosity, our exploration of nature, may unwittingly lead us into an irretrievable disaster. But they argue we have no alternative.[9] Such a position is, of course, a self-fulfilling prophecy.

I would differentiate among what might be called physical feasibility, logical feasibility, and political feasibility.

I believe that actual physical restraint is in principle feasible. There are two evident avenues of control: the power of the purse and access to instruments. Control of funding is indeed already a powerful means for control of the directions of inquiry for better or worse. To the extent that there exists a multiplicity of sources of support, such control is porous and incomplete, but it is clearly a first line of restraint.

Research today cannot be done with household tools. It is difficult to imagine, for instance, any serious research on aging that would not require the use of radioisotopes or an ultracentrifuge or an electron microscope. The use of isotopes is already regulated for other reasons. Access to electron microscopes could, in principle, be regulated, albeit at very real cost to our current concepts of intellectual freedom.

An immediately related, important aspect of any policy of restraint concerns the distinctions to be made about the nature of research. Can we logically differentiate research on aging from general basic biologic studies? I expect we cannot in any simple, absolute sense. Yet obviously the people who established the National Institute of Aging must have believed that there is a class of studies which deserves specific support under that rubric. Indeed, distinctions of this sort are made all the time by the various institutes of National Institutes of Health in deciding which grant applications are potentially eligible for their particular support. Pragmatically, and with some considerable margin of error, such distinctions can be and are made.

It is frequently claimed that the "unpredictability" of the outcome of research makes its restraint, for social or other purpose, illogical and indeed futile. However, the unpredictability of a research outcome is not an absolute but is both quantitatively and qualitatively variable.

In more applied research within a field with well-defined general principles, the range of possible outcomes is surely circumscribed. In more fundamental research, in wholly new fields remote from prior human experience—as in the cosmos, or the subatomic world, or the core of the planet—wholly novel phenomena may be discovered. But, for instance, even in a fundamental science such as biology, most of the overt phenomena of life have been long known.

The basic principles of heredity were discovered by Mendel a century ago and were elaborated by Morgan and others early in this century. The understanding of genetic mechanism, the reduction of genetics to chemistry, had to await the advent of molecular biology. This understanding of mechanism has now provided the potential for human interventions, for genetic engineering, but it has not significantly modified our comprehension of the genetic basis of biological process.[10]

The path of modern biology will surely lead to further understanding of biological mechanism, with subsequent application to medicine and agriculture (and accompanying social impact). But it would seem likely that only within the central nervous system may there be the potential for wholly novel—and correspondingly wholly unpredictable—process. Even there, the facts of human psychology and the subjective realities of human consciousness have long been familiar to us, albeit the underlying mechanisms are indeed obscure.

Political feasibility is, of course, another question. The constituency most immediately affected is, of course, the scientific. And despite our protestations and alarms this community does have real political influence. It would seem unlikely to me that a policy of scientific restraint could be adopted in any sector unless a major portion of the scientific community came to believe it desirable.

For this to happen, that community will clearly have to become far more alert to, and aware of, and responsible for the consequences of their activities. The best discipline is self-discipline. Scientists are keenly sensitive to the evaluations of their peers. The scientific community and the leaders of our scientific and technical institutions will have to develop a collective conscience; they will have to let it be known certain types of research are looked upon askance, much as biological warfare research is today; it needs to be understood that such research will not be weighed in considerations of tenure and promotion; societies need to agree not to sponsor symposia on such topics. All of these and similar measures short of law could indeed be very effective.

I am well aware of the dangers implicit in such forms of cultural restraint. But I think we really must look at the dangers we face in the absence of self-restraint. Do we accept only the restraint of catastrophe?

If we are to consider this position, we must do so in a forthright manner. We must be willing to explore the vistas exposed if we lower conventional taboos and sanctions. We may not at first enjoy what we see, but at least we will have a better perception of the available alternatives. Any attempt to limit the freedom of scientific inquiry will surely involve what will appear, at least at first, to be quite arbitrary distinctions—judgmental decisions, the establishment of boundaries in gray and amorphous terrain. These are, however, familiar processes in our society, in the courts, in the legislatures. Indeed, most of us are familiar with such problems in our educational activities. The selection of new faculty, the award of tenure, the assignment of grades are clearly judgmental decisions.

In science we try with some success to elude the necessity for such very human judgments. Indeed, one suspects that many persons go into science precisely to avoid the necessity for such complex decisions—in search of a domain of unique and unequivocal answers of enduring validity. And it is painful to see the sanctuary invaded.

Admittedly it is difficult to achieve consensus on the criteria for judgmental decisions. Such consensus is all the more difficult in the sphere of international activities such as science which involve participants from diverse cultures and traditions.

Conversely there are many persons who prefer the more common, perhaps the more human world of ambiguity and compromise and temporally valid judgments and who resist the seemingly brutal, life and death, cataclysmic types of decision increasingly imposed upon society by the works of science. And science and scientists cannot stand wholly aloof from these latter dilemmas—for science is a human activity and scientists live in the human society. We cannot expect the adaptation to be wholly one-sided.

Even if, at best, we can only slow the rate of acquisition of certain areas of knowledge, such a tactic would give us more time to prepare for social adaptation—if we mobilize ourselves to use that time.

The Case for Restraint

The view one exposes by lifting that sanction we label freedom of inquiry is frankly gloomy. It would seem that we are asked to make thorny decisions and delicate differentiations, to relinquish long-cherished rights of free inquiry, to forego clear prospects of technological progress. And it would seem that all these concessions stem ultimately from recognition of human frailty and from recognition of the limitations of human rationality and foresight, of human adaptability and even good will. Just such recognitions have already spawned many of our institutions and professions—religions, the law, government, United Nations—yet all of these are as imperfect as the world they are designed to restrain and improve.

At each level of human activity, whether individual, group, or national, we continually struggle to find acceptable compromises between the freedom to pursue varied courses and goals and the conflicts that arise when one person's actions run contrary to another's. In a crude sense the greater the power available to an entity, the more limitations must be imposed upon its freedom if conflict is to be averted. Ideally such limits are internalized through education and conscience, but we all understand the inadequacy of that process.

In short, we must pay a price for freedom, for the toleration of diversity, even eccentricity. That price may require that we forego certain technologies, even certain lines of inquiry where the likely application is incompatible with the maintenance of other freedoms. If this is so and if we can recognize and understand this, perhaps we can, as scientists, be more accepting.

Some will argue that knowledge simply provides us with more options and thus that the decision point should not be at the acquisition of knowledge but at its application.

Such a view, however ideal, overlooks the difficulty inherent in the restriction of application of new knowledge, once that knowledge has become available in a free society. Does anyone really believe, for instance, that knowledge permitting an extension of the human life span would not be applied once it were available?

One must also recognize again that the very acquisition of knowledge can change both the perceptions and the values of the acquirer. Could, for instance, deeper knowledge of the realities of human genetics affect our commitment to democracy?

It may be argued that the cost, however it may be measured, of impeding research would be greater to a society than the cost of impeding application. Perhaps so. This issue could be debated, but it must be debated in realistic terms with regard for the nature of real people and real society and with full understanding that knowledge is indeed power.

Although the nature of the measures necessary to restrict the application of knowledge has seldom been analyzed, the measures needed would surely be dependent upon the size of investment required to apply the knowledge, as well as on the form of and the need for the potential benefits of the knowledge, among other things. The compatibility of such restrictive measures with the principles of a democratic society would need to be considered. Restriction of nuclear power may be a case in point.

Alvin Weinberg has developed the concept of the technological fix as the simple solution to cut the Gordian knot of complex social problems. However, we seem to be discovering that the application of one technological fix seems to lead us into another technological fix. For example, the development of antibiotics and other triumphs of modern medicine has led to the tyranny of overpopulation. In efforts to cope with overpopulation by more intensive agriculture, we develop pesticides, herbicides and other chemicals which increase the level of environmental carcinogenesis. And so on.

The moral is that we cannot ignore the social and cultural context within which the technology is deployed. In retrospect we can see that in the cultural and social context of the seventeenth, eighteenth, and nineteenth centuries the consequences of technological innovation were most often benign. Whether because of change in the society and culture or change in the nature and effectiveness of technology, at some time in the twentieth century the balance began to shift and by now our addiction to technology begins to assume an unpleasant cast.

We are indeed addicted to technology. We rely ever more upon it and thus become its servant as well as its master. It has led to human populations insupportable without its aid. Further, new technologies shape our perceptions; they spawn expectations of change or stir deep fears of disaster. They dissociate us from the past and becloud the shape of the future. Even the oldest boundary conditions of humanity fall as we leave the planet and as we plan to reshape our genes.

Our academic institutions and our professional societies foster and promote science. To some degree they also have concern for its consequences, but it is a minor aspect. The principle that one should separate agencies which promote and agencies which regulate may apply here.

But where then is the balance, the necessary check to the force of scientific progress? Is the accumulation of knowledge unique among human activities—

an unmitigated good that needs no counterweight? Perhaps that was true when science was young and impotent, but hardly now. Yet we lack the institutional mechanisms for regulation.

Our experience with constraint upon science has hardly been encouraging. From the Inquisition to Lysenko such constraint has been the work of bigots and charlatans. Obviously, if it is to be done to a good purpose, any restraint must be informed, both as to science and as to the larger society on which science impacts.

The acquisition of knowledge is a human, a social, enterprise. If we, through the relentless, single-minded pursuit of new knowledge so destabilize society as to render it incapable—or unwilling—to continue to support the scientific enterprise, then we will have, through our obsession, defeated ourselves.

At Caltech and the many other academic institutions, we have now, *culturally*, cloned Galileo a millionfold. We have nurtured this Galilean clone well; we award prizes and honors to those most like the original. No doubt this clone has been most beneficial for humanity, but perhaps there is a time for Galileos. Perhaps we need in this time to start another clone.

References

[1]R. A. Millikan, "Alleged Sins of Science," *Scribners Magazine*, 87 (2) (1930): 119–130.

[2]Frederick Soddy, *Science and Life* (London: John Murray, 1920).

[3]Precisely what evidence Dr. Millikan had in mind is uncertain. However, it was generally appreciated that the efficiency of nuclear transformation by the charged particles then in use was so low that there was no significant prospect of a net release of energy. No practical chain reaction could yet be envisaged.

[4]A. V. Hill in his presidential address to the British Association for the Advancement of Science in 1952, referring to the population problem, said, "If ethical principles deny our right to do evil in order that good may come, are we justified in doing good when the foreseeable consequence is evil?"

[5]See A. S. Krass, "Laser Enrichment of Uranium: The Proliferation Connection," *Science*, 196 (1977): 721–731; also B. M. Casper, "Laser Enrichment: A New Path to Proliferation?" *Bulletin of Atomic Scientists*, 33 (1) (1977): 28–41.

[6]See T. B. H. Kuiper and M. Morris, "Searching for Extraterrestrial Civilizations," *Science*, 196 (1977): 616–621; also B. Murray, S. Gulkis, and R. E. Edelson, "Extraterrestrial Intelligence: An Observational Approach," *Science*, in press.

[7]C. Sagan (ed.), *Communication with Extraterrestrial Intelligence (EETC)* (Cambridge, Mass.: MIT Press, 1973).

[8]Conceivably, we might not be given this choice if an advanced civilization were determined to contact us. At present however, it would seem to be our option.

[9]This is not a new perception. "The world is now faced with a self-evolving system which it cannot stop. There are dangers and advantages in this situation. . . . Modern science has imposed upon humanity the necessity for wandering. Its progressive thought and its progressive technology make the transition through time, from generation to generation, a true migration into uncharted seas of adventure. The very benefit of wandering is that it is dangerous and needs skill to avert evils. We must expect, therefore, that the future will disclose dangers. It is the business of the future to be dangerous; and it is the merit of science that it equips the future for its duties," wrote A. W. Whitehead in *Science and the Modern World*.

[10]Indeed the failure to discover a new class of phenomena underlying genetics has been most disappointing to some. See Gunther S. Stent, "That Was the Molecular Biology That Was," *Science*, 160 (1968): 390–395.